ScienceDirect

Icarus

Volume 191, Issue 2, Supplement, 2007, Pages 586-597

A crater and its ejecta: An interpretation of Deep Impact ☆

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https://doi.org/10.1016/j.icarus.2006.08.035

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Abstract

We apply recently updated scaling laws for impact cratering and ejecta to interpret observations of the Deep Impact event. An important question is whether the cratering event was gravity or strength-dominated; the answer gives important clues about the properties of the surface material of Tempel 1. Gravity scaling was assumed in pre-event calculations and has been asserted in initial studies of the mission results. Because the gravity field of Tempel 1 is extremely weak, a gravity-dominated event necessarily implies a surface with essentially zero strength. The conclusion of gravity scaling was based mainly on the interpretation that the impact ejecta plume remained attached to the comet during its evolution. We address that feature here, and conclude that even strength-dominated craters would result in a plume that appeared to remain attached to the surface. We then calculate the plume characteristics from scaling laws for a variety of material types, and for gravity and strength-dominated cases. We find that no model of cratering alone can match the reported observation of plume mass and brightness history. Instead, comet-like acceleration mechanisms such as expanding vapor clouds are required to move the ejected mass to the far field in a few-hour time frame. With such mechanisms, and to within the large uncertainties, either gravity or strength craters can provide the levels of estimated observed mass. Thus, the observations are unlikely to answer the questions about the mechanical nature of the Tempel 1 surface.

Introduction

When the Deep Impact spacecraft slammed into Comet Tempel 1, a compressive shock was generated that swept into the comet's surface material. The resulting pressures were very high near the impact point, but diminished rapidly as the shock propagated. If the event unfolded along lines observed in decades of cratering experiments, material in regions more or less beneath the impact point was driven downward and compressed. In regions further from the impact point, the flow velocity was primarily outward and upward. Material in those regions was displaced, compacted or ejected. The result of the material flow was an expanding crater with a plume of ejecta tracking the crater edge. Then the growth of the crater was slowed and arrested; within a few minutes if by gravitational forces, or as quickly as a few seconds if by mechanical strength of the target material. Depending on the relative importance of these two factors, the crater is said to have formed in the gravity regime, or in the strength regime. Alternate terminology is that the crater was gravity-scaled or strength-scaled.

Understanding the relative effects of gravity and strength is important because they can tell a great deal about the mechanical properties of the comet nucleus material. Tempel 1 is a small body with a gravity field so weak that one could literally jump off it. Therefore, gravity could be the dominant mechanism in determining the final crater only if the comet nucleus material has negligible strength. Most predictions of crater size for Deep Impact (Schultz et al., 2005, Richardson et al., 2005) were based on gravity scaling, perhaps because it provides a useful upper limit on crater size. Post-event analysis also asserted that the event was gravity scaled (A'Hearn et al., 2005).

We present a summary of the scaling laws of cratering mechanics including improvements to constants based on a variety of recent impact experiments. The scaling laws are described briefly in the next section, and then are used to model the evolution of the ejecta plume produced by Deep Impact. The calculations are used to determine the properties of the plume for various assumed material types for the comet. The results are compared with observations to infer the nature of the Deep Impact event, and to constrain the properties of the Tempel 1 surface material.

Section snippets

Scaling laws for impact cratering

In a high-speed impact, the coupling of the impactor energy and momentum into the target material occurs over a region whose size is the same order as the impactor size. Then the final crater size is generally many times larger than the impactor. So, to a good approximation, the impact occurs as a point source. Theoretical analyses (Holsapple and Schmidt, 1987, Housen et al., 1983, Holsapple, 1993) of cratering mechanics show that the rate at which the crater grows, its time of formation, the …

Cratering and ejecta for Deep Impact

Adopted values for the parameters for Deep Impact (Belton et al., 2005, Richardson et al., 2005) are given in Table 2. Using these parameters, results for each of the scaling types can be calculated. Our primary focus is on the sand gravity scaling and on cohesive soils, because the low density of the comet nucleus would seem to rule out the nonporous materials. However, for comparison, we do include an upper limit of water, and a lower limit of a soft rock material, and some rough estimates …

The appearance of the ejecta plume

In this section, the scaling laws are used to obtain the ejecta mass and velocity characteristics and, from that, the plume evolution. An equivalent vertical impact and 45° ejecta angle were assumed. …

Comparison to observations

The plume appearance, shape and brightness have been measured in a number of ways at different wavelengths, from ground and space-based stations. Those measurements have been used to estimate the total ejecta mass, and the brightness history. Unfortunately, the pixel sizes are on the order of 100 km, so no detail could be seen.

In Harker et al. (2005) the ejecta mass is estimated to be in the range of 7.3×10^4 to 1.5×10^6 kg. Sugita et al. (2005) give estimates from a lower limit of 10^5 kg to an …

Summary and conclusions

Calculations presented here show that if the Tempel 1 nucleus surface material has no cohesion, and if the impact were like conventional soil cratering, the initial mass in the ejecta cloud would be of order 10^7 kg, but 98.6% of it would return to the comet surface within a few hours. Only 2.5×10^5 kg would be observable at the brightness peak and only 1.4×10^5 kg would escape and remain in the expanding plume after about 4 h.

However, comets are known to accelerate material to velocities of 100's of …

Acknowledgements

The authors acknowledge support by NASA Grant 05-PGG05-112 and NASA contract NNH05CC23C. …

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References (26)

K.A. Holsapple
The scaling of impact phenomenon
Int. J. Impact Eng. (1987)

K.R. Housen *et al.*
Impact cratering on porous asteroids
Icarus (2003)

R.M. Schmidt *et al.*
Some recent advances in the scaling of impact and explosion cratering
Int. J. Impact Eng. (1987)

S. Yamamoto *et al.*
Velocity measurements of impact ejecta from regolith targets
Icarus (1997)

M.F. A'Hearn *et al.*
Deep Impact: Excavating Comet Tempel 1
Science (2005)

M.J.S. Belton *et al.*
Deep Impact: Working properties for the target nucleus—Comet 9P/Tempel 1
Space Sci. Rev. (2005)

M.J. Cintala *et al.*
Ejection–velocity distributions from impacts into coarse-grained sand
Meteorit. Planet. Sci. (1999)

V. Gromov
Physical and mechanical properties of lunar and planetary soils
Earth Moon Planets (1998)

D.E. Harker *et al.*
The dust grains of 9P/Tempel 1 before and after the encounter with Deep Impact
Science (2005)

K.A. Holsapple
The scaling of impact processes in planetary sciences
Annu. Rev. Earth Planet. Sci. (1993)

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